

# The UV high resolution spectrum of A-type supergiants\*

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**Summary.** A study of all the A-supergiants observed with IUE at high resolution shows that they can be divided into two groups: stars which show evidence of wind and mass-loss, and stars which do not show these characteristics. In the first group the resonance lines of Mg II, Fe II, Si II, C II are asymmetric, showing variable shortward shifted components. In the second group, formed by the faintest stars, these lines are symmetric.

The velocity of the most shortward shifted component observed in the Fe II lines and the terminal velocity remain constant in most of the stars. However, the intermediate shortward shifted components of Fe II lines vary with time, indicating the ejection of shells from time to time or the existence of CIR (Corotating Interaction Regions).

The terminal velocity decreases with increasing escape velocity which is not in agreement with the radiation-driven-wind theory. However time-monitoring of several stars would be necessary to confirm this assertion because of the variations in the terminal velocity detected in the faintest mass-losing stars.

**Key words:** stellar winds – mass loss –supergiant stars

## 1. Introduction

A-supergiants occupy a region in the Hertzsprung-Russell (HR) diagram where evolution is rapid (Wolff, 1983). This quick evolution and the absence of A-supergiants in the solar neighbourhood are the main causes for the fact that the UV spectra of only a few A-supergiants have been studied intensively. As a matter of fact, very little systematic work (except for  $\alpha$ -Cyg) has been carried out to study the time-variability, the structure of the wind, the mass-loss rates, . . . in the A-supergiants as a whole.

Only four A-supergiants have been studied in detail in the UV range: HD 21389, HD 59612,  $\eta$  Leo (HD 87737) and  $\alpha$ -Cyg (HD 197345). In 1980 Praderie et al. performed the first study of these stars with the International Ultraviolet Explorer (IUE);

they found evidence of mass-loss in three of the stars ( $\alpha$ -Cyg, HD 21389 and HD 59612). These stars showed a shortward shifted broad absorption in the resonance lines of Mg II, Fe II, C II and Si II.

The brightest of the stars,  $\alpha$ -Cyg, presents a peculiar asymmetric profile in the Mg II resonance lines. These lines are characterized by a shortward shifted broad saturated core, a sharp violet edge, and the absence of emission longward of the rest-wavelength as defined by the interstellar absorption feature. This type of profile has been observed also in the C II and Si II lines. In order to reproduce this profile Kunasz and Praderie (1981) developed a semi-empirical model of a wind in which the Mg II lines are treated by means of an NLTE two-level atom in an expanding, spherically symmetric atmosphere. To explain the absence of the expected emission in the P-Cygni type profile, they proposed that the P-Cygni emission component cancels against photospheric absorption on the longward side of the line center, and against both line-of-sight scattering and absorption in the vicinity of the photosphere to produce the sloping longward side of the violet-shifted absorption profile, similar to the observations. Kunasz and Morrison (1982) and Kunasz et al. (1983) applied the same computational scheme to interpret the H $\alpha$  profile of  $\alpha$  Cyg, and the Mg II and H $\alpha$  profiles of HD 21389, respectively.

On the other hand Barbier et al. (1978) reported several shortward shifted components in the Fe II lines of  $\alpha$  Cyg, from Copernicus data.

No systematic study has been carried out in order to see if the so-called  $\alpha$  Cyg profile observed in the Mg II lines and the components observed in the Fe II resonance lines can be formed in the same type of spherically symmetric wind.

Our purpose in studying the A-supergiants observed with IUE is to complete the scheme outlined by Praderie et al. (1980), by analysing all the UV high dispersion spectra available, and specially the Mg II and Fe II resonance lines.

## 2. Stars studied and data reduction

In Table 1 are listed the 13 stars which constitute our sample. Only one of the A-supergiants observed at high dispersion with IUE has been excluded: HD 30353. This star is a hydrogen-poor spectroscopic binary (Heard et al., 1955; Drilling and Schonberner, 1982) which has been observed only at phases 0.40 and 0.90 and the spectra available in the IUE Data Bank are contaminated by the spectrum of the secondary star.

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\* Based on data collected by the International Ultraviolet Explorer, de-archived from the Villafranca Data Archive of the European Space Agency.

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**Table 1.** A-Supergiants observed with IUE

Star	M.K. class	Images studied		
		L.W.P.	L.W.R.	S.W.P.
HD 46300	A0 Ib		3757	16436
HD 87737	A0 Ib		2915	3307
( $\eta$ Leo)				
HD 59612	A5 Ib		2913	3305
(HR 2874)			3758	4443
			3917	
			9047	
HD 207260	A2 Iab	3078	9001	16105
HD 14433	A1 Ia		5973	
HD 21389	A0 Iab		2929	3332
(HR 1040)			3773	4399
				4498
HD 223960	A0 Ia		8994	
HD 14489	A2 Ia		16763	21813
HD 12953	A1 Ia		5972	
			8998	
HD 17378	A5 Ia		9042	
HD 92207	A0 Ia		10515	
HD 223385	A3 Ia		16761	20995
(6 Cas)				
HD 197345	A2 Ia	3079	1723	3330
( $\alpha$ Cyg)			2583	
			2626	
			4825	
			5975	
			7584	
			7760	
			9020	
			9040	
			9056	

In Table 1 we give for each star the images we selected to use for our study. We have chosen unsaturated, well exposed images. Note that only eight stars have images both in short and long wavelengths; therefore when studying the highly ionized lines our sample will be reduced.

In Table 2 are listed the main properties of the studied stars. The visual absolute magnitude  $M_v$  has been extracted from Humphreys (1978); the bolometric correction BC and the effective temperature  $T_{\text{eff}}$  have been interpolated from Schmidt-Kaler (1982) knowing the spectral type; the bolometric magnitude  $M_b$  has been obtained from  $M_v$  and BC; the mass  $M$  has been interpolated from De Loore (1977); the rotational velocity:  $V \sin(i)$  has been extracted from Hoffleit (1982);  $\Gamma$  is the ratio of stellar to Eddington luminosity:

$$\Gamma = \frac{\sigma_e L}{4\pi G M c}$$

where  $L$  is the stellar luminosity, and  $\sigma_e$  is the electron scattering opacity. We adopt  $\sigma_e = 0.33$  (Abbott, 1978). Finally the effective escape velocity from the stellar surface  $V_e$  has been computed using the formula:

$$V_e = \sqrt{1 - \Gamma} \sqrt{\frac{2GM}{R}}$$

All data have been processed at VILSPA and very old images have been reprocessed with the current software.

It is well known that the IUE data have an uncertainty in the wavelength scale which can amount up to 0.5 Å. To circumvent this problem we have measured the wavelengths of some interstellar lines (see Table 3). We have corrected each spectrum by the average value of the differences between laboratory and measured wavelengths. The standard deviation from the average amounts to 0.08 Å ( $\approx 9 \text{ km s}^{-1}$  at the 2802 Mg II line). There are several stars in which the lines selected are not clearly interstellar (they are wider than the instrumental profile of IUE) and in such a case we have compared the spectrum with the spectrum of HD 46300 to fit the wavelength scale (HD 46300 shows a great number of narrow lines).

We have drawn local continua in the regions of interest by linear interpolation between selected windows. These windows are the same as used by Praderie et al. (1980).

### 3. Description of the spectra

We will restrict ourselves to the examination of the spectral lines listed in Table 3. These lines can be split into highly ionized and singly ionized species, the latter being very sensitive to the velocity field in the A-supergiants (Praderie et al., 1980).

The UV continuum in the 1200–1400 Å range is underexposed in the coolest stars of our sample and therefore the lines of Si II (UV mult. 3) have been excluded from our study.

The presence of C IV and Si IV in A-supergiants has given rise to controversy. In 1980, Underhill discovered sharp, undisplaced C IV emission lines in HD 21389; she suggested that their sporadic appearance might be related to the presence of hot plasma as for late-type supergiants. However in their work, Praderie et al. (1980) did not report the existence of any trace of emission nor of absorption in  $\alpha$  Cyg, HD 21389 and HD 59612, at the wavelengths of the C IV resonance lines.

In agreement with Praderie et al. (1980) we have not found *highly ionized species* (C IV, Si IV, N V, He II 1640) in our sample, except in 6 Cas (HD 223385) (see Sect. 7). Neither HD 46300, nor HD 207260, nor HD 14489 show C IV lines. However the absorption features located near the wavelengths of C IV lines seem to become broader when the luminosity of the stars increases. These absorption features are probably due to blends of metallic lines.

Recently, Grady and Imhoff (1985) have shown that there are two weak camera artifacts which fall by coincidence at nearly identical offsets from the C IV doublet; this might clarify the nature of the emission observed by Underhill (1980).

By studying the Si II, C II, Mg II and Fe II lines we find that we can subdivide our sample into two groups.

#### 3.1. Group I: Stars which do not show evidence of mass-loss

In these stars the resonance lines of the singly ionized species show symmetric absorption profiles centered at zero-velocity. Among them the Fe II lines are the narrowest, while the Mg II lines are quite broad (see Figs. 1, 2, 3 and 4).

Stars included in this group are HD 46300 and HD 87737. Both are Ib supergiants as is HD 59612 (see Table 2). However we do not classify HD 59612 in this group (see below).

**Table 2.** Main characteristics of the stars studied

Star	S.T.	$M_v$ (a)	B.C. (b)	$M_b$	$M (M_\odot)$ (c)	$T_{\text{eff}} \text{ (K)}$ (d)	$R (R_\odot)$ (e)	$V \sin(i)$ (e)	$\sqrt{1 - \Gamma}$	$V_{\text{esc}} \text{ (km s}^{-1}\text{)}$ (f)
HD 46300	A0 Ib	−4.8	−0.41	−5.2	8	9730	34	17	0.99	297
HD 59612	A5 Ib	−5.1	−0.13	−5.3	7	8510	39	37	0.99	259
HD 87737	A0 Ib	−5.3	−0.41	−5.7	9	9730 (10350)	41 (38)	20	0.98 (0.98)	283 (295)
HD 207260	A2 Iab	−6.7	−0.28	−7.0	14	9080	89	33	0.96	235
HD 14433	A1 Ia	−7.0	−0.32	−7.3	15	9230	101	–	0.94	194
HD 21389	A0 Iab	−7.1	−0.41	−7.5	16	9730	99	6	0.94	233
HD 223960	A0 Ia	−7.1	−0.41	−7.5	16	9730	99	–	0.94	233
HD 14489	A2 Ia	−7.6	−0.28	−7.9	18	9080	135	25	0.92	208
HD 12953	A1 Ia	−7.9	−0.32	−8.2	22	9230	167	18	0.89	199
HD 17378	A5 Ia	−7.9	−0.13	−8.0	19	8510	164	37	0.83	174
HD 92207	A0 Ia	−8.0	−0.41	−8.4	22	9730	150	56	0.89	211
HD 223385	A3 Ia	−8.3	−0.21	−8.5	22	8770	193	50	0.88	184
HD 197345	A2 Ia	−8.4	−0.28	−8.7	23	9080 (8604)	195 (219)	21	0.86 (0.86)	182 (172)

Values have been extracted from:

- (a) Humphreys, 1978; except for HD 59612 and HD 87737. The visual absolute magnitude of HD 59612 has been interpolated from Code et al. (1976) and Cramer & Maeder (1979). The value for HD 87737 has been extracted from Kondo et al. (1976).  
 (b) Interpolated from Schmidt-Kaler (1982) knowing the MK class.  
 (c) De Loore (1977).  
 (d) Schmidt-Kaler (1982). Values in parentheses have been extracted from Lamers et al. (1978).  
 (e) Hoffleit (1982)  
 (f) These values have been estimated from  $M_b$  and  $T_e$ .

### 3.2. Group II: A-supergiants which show evidence of mass-loss

The spectrum of the stars of this group can be described as follows:

#### 3.2.1. Mg II lines

These lines show two different types of profiles characteristic of mass outflow. In some stars the Mg II lines are asymmetric with no emission longward of the zero-velocity feature and with a sharp shortward edge (HD 92207, HD 14489 and  $\alpha$  Cyg). In other stars the Mg II profiles are composed of several deep shortward shifted components (HD 17378, HD 12953, HD 21389, HD 59612 and HD 223960). In addition to these two main groups there are two stars, HD 14433 and HD 207260, whose 2802 Å Mg II line seems to be split in three components (including the interstellar feature) while the 2795 Å line of Mg II is not split. These profiles are presented in Fig. 1.

#### 3.2.2. Fe II lines

The Fe II spectrum of the stars of Group II is characterized by the presence of sharp shortward shifted absorption components. (See Fig. 2). In HD 197345 ( $\alpha$  Cyg), HD 92207, HD 14433, HD 12953, HD 17378, HD 59612 and HD 207260, the Fe II lines have at least two intense components which are blended and shortward shifted. However there are several stars in this group (HD 14489, HD 21389 and HD 223960) whose Fe II lines are asymmetric and only slightly shortward shifted ( $\approx 20 \text{ km s}^{-1}$ ). These last stars are not the less luminous stars of the group, and their Mg II lines are clearly asymmetric.

#### 3.2.3. C II, Si II and Al II lines

These lines are very similar to the Mg II lines except in HD 21389 where C II and Si II are symmetric. The available spectra of HD 59612 are underexposed in that region. The spectral regions of the C II and Si II resonance lines are shown in Figs. 3 and 4.

The identification of components in the profiles of these lines is difficult because of blending with some intense metallic lines due to Fe III, Fe II, Cu II, Ni II and P II.

The Al II lines are similar to the Mg II lines. However the presence of a resseau mark blurs the profile and makes the study of the Al II resonance lines very difficult.

In Figs. 3 and 4 we compare the profiles of C II and Si II resonance lines in a star of group I (HD 46300) and another star of group II (HD 14489). The Si II 1533 Å line shows the asymmetric profile characteristic of the wind although this line arises from an excited level (0.04 eV). This behaviour is shown also by HD 197345 and HD 207260.

### 4. Components in the line profile

As pointed out in the previous section, one of the characteristics of the line profiles in A-supergiants is the presence of discrete shortward shifted components. We have studied these shortward shifted components in the Fe II and Mg II profiles. The nature of the data (resolution, possible blending with photospheric lines) makes difficult to say whether these components are symmetric or not. Therefore we have measured the position of the center of the component at half intensity and computed the velocity shift relative to the rest position of the line.

**Table 3.** Lines studied

Ion	Mult.	Wavelength	EPI (eV)	EPu (eV)	Remarks	Ion	Mult.	Wavelength	EPI (eV)	EPu (eV)	Remarks
N v	1	1238.800	0.00	9.97		Fe II	1	2585.876	0.00	4.77	IS, *
		1242.778	0.00	9.93				2598.369	0.05	4.80	
C II	1	1334.532	0.00	9.25	IS			2599.395	0.00	4.75	IS
		1335.663	0.01	9.25				2607.086	0.08	4.82	
		1335.708	0.01	9.25	IS			2611.873	0.05	4.77	
Si IV	1	1393.755	0.00	8.86				2613.820	0.11	4.83	
		1402.770	0.00	8.80				2617.618	0.08	4.80	
Si II	2	1526.708	0.00	8.09	IS			2620.408	0.11	4.82	
		1533.432	0.04	8.09				2621.669	0.12	4.83	*
C IV	1	1548.185	0.00	7.97				2625.664	0.05	4.75	
		1550.774	0.00	7.96				2628.291	0.12	4.82	*
He II	H	1640.474	40.64	48.16				2631.045	0.11	4.80	
Al II	2	1670.787	0.00	7.39	IS			2631.321	0.08	4.77	
Fe II	3	2327.391	0.08	5.39		Mn II	1	2576.107	0.00	4.79	IS
		2332.798	0.05	5.34				2593.731	0.00	4.76	IS
		2338.798	0.11	5.39				2605.697	0.00	4.74	IS
		2343.495	0.00	5.27	IS	Fe II	62	2692.826	0.98	5.57	
		2344.278	0.12	5.39				2709.373	1.04	5.59	
		2348.300	0.008	5.34				2716.683	0.98	5.52	
		2359.111	0.11	5.34				2724.879	1.04	5.57	
		2364.825	0.05	5.27				2730.735	1.07	5.59	
		2380.757	0.08	5.27				2737.196	1.09	5.59	*
								2746.487	1.07	5.57	
								2749.324	1.04	5.52	
Fe II	2	2366.864	0.00	5.21	IS			2755.733	0.98	5.46	
		2373.733	0.00	5.20	IS	Fe II	63	2714.414	0.98	5.53	*
		2382.034	0.00	5.18	IS			2727.538	1.04	5.56	
		2383.060	0.05	5.23				2736.968	1.07	5.53	
		2388.629	0.05	5.21				2739.545	0.98	5.49	*
		2395.416	0.05	5.26				2746.978	1.04	5.53	
		2395.627	0.005	5.20				2749.182	1.07	5.56	
		2399.237	0.008	5.23				2749.482	1.09	5.58	
		2404.430	0.11	5.24				2761.813	1.09	5.56	
		2404.882	0.08	5.21				2768.940	1.07	5.53	
		2406.660	0.11	5.23				2772.719	1.04	5.49	
		2410.521	0.11	5.23		Mg II	1	2795.523	0.00	4.41	IS
Fe II	161	2411.062	0.12	5.24				2802.698	0.00	4.40	IS
		2413.308	0.12	5.23		Mg I	1	2852.120	0.00	4.33	IS

(1) Air wavelengths if  $\lambda > 2000 \text{ \AA}$   
 Vacuum wavelengths if  $\lambda < 2000 \text{ \AA}$

IS Interstellar lines used for wavelength calibration  
 \* Fe II lines selected to study shortward shifted components

#### 4.1. Fe II lines:

We have selected a small group of Fe II lines to study their components (see Table 3). These lines are characterized by their large intensity and the absence of other strong metallic lines in their vicinities.

Nearly all the stars present two or more components clearly resolved, although not all the components are observed in all the lines. We have considered as real components only those which appear in at least five of the seven selected Fe II lines. Their shifts (in  $\text{km s}^{-1}$ ) are given in Table 4.

#### 4.2. Mg II lines

The components of the Mg II lines must be treated carefully because they might be blended with other intense lines. For instance: there are some Fe I and Fe II lines which can be confused with Mg II components. In Table 5 we have listed these possible blending lines, their wavelengths and their shifts relative to the corresponding Mg II line position.

Although components in the Mg II lines have only been observed in a small group of stars (see Table 4), their velocities agree with those of the Fe II components. However there are some

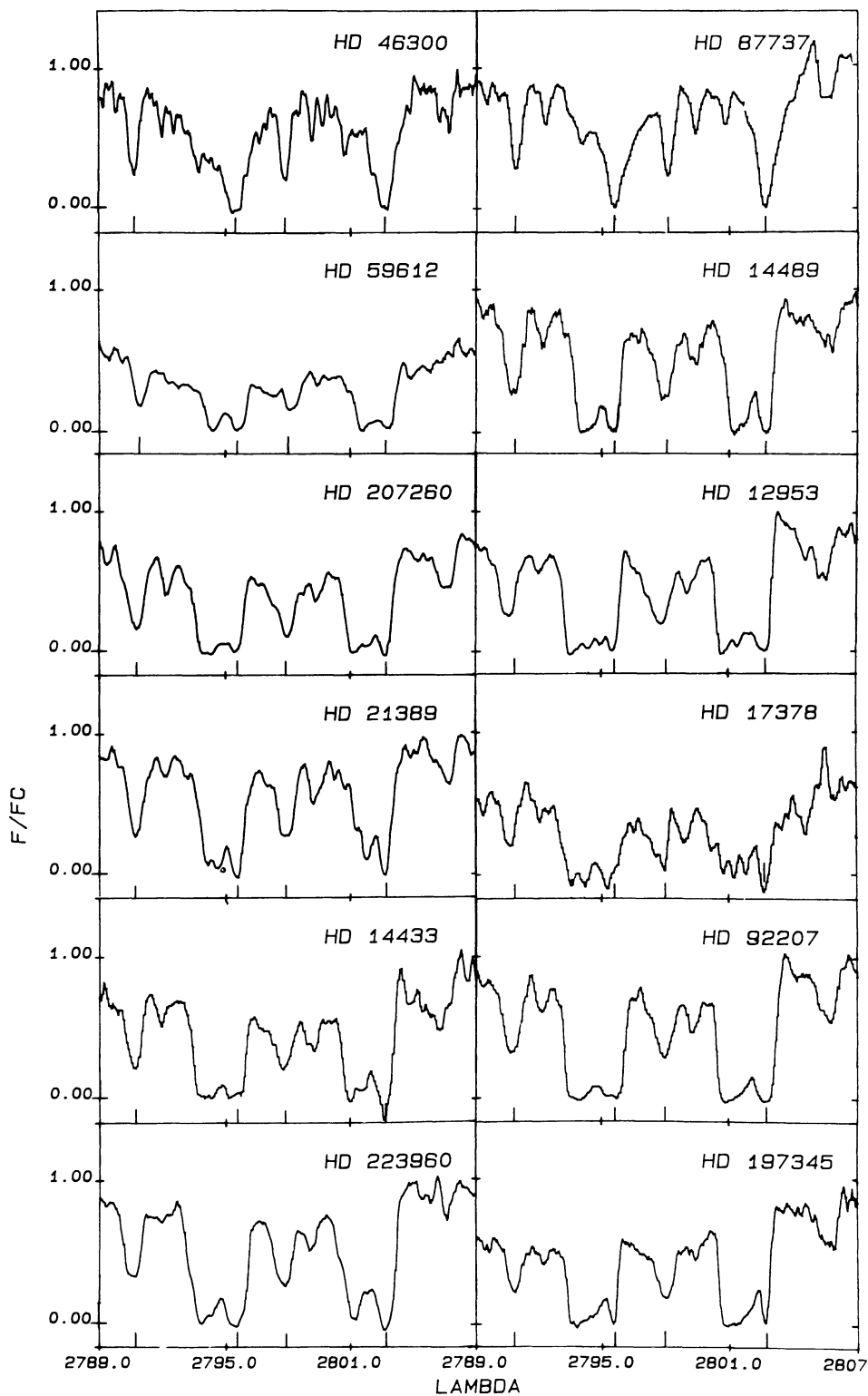


Fig. 1. Mg II lines in the A-supergiants studied (except 6-Cas). The rest wavelengths of the lines of mult. 1 and mult. 3 are indicated by long ticks on the abscissa

discrepancies:

a) In HD 17378 the most shortward shifted Mg II component is observed at  $-208 \text{ km s}^{-1}$ . However no component at this velocity has been detected in the Fe II lines.

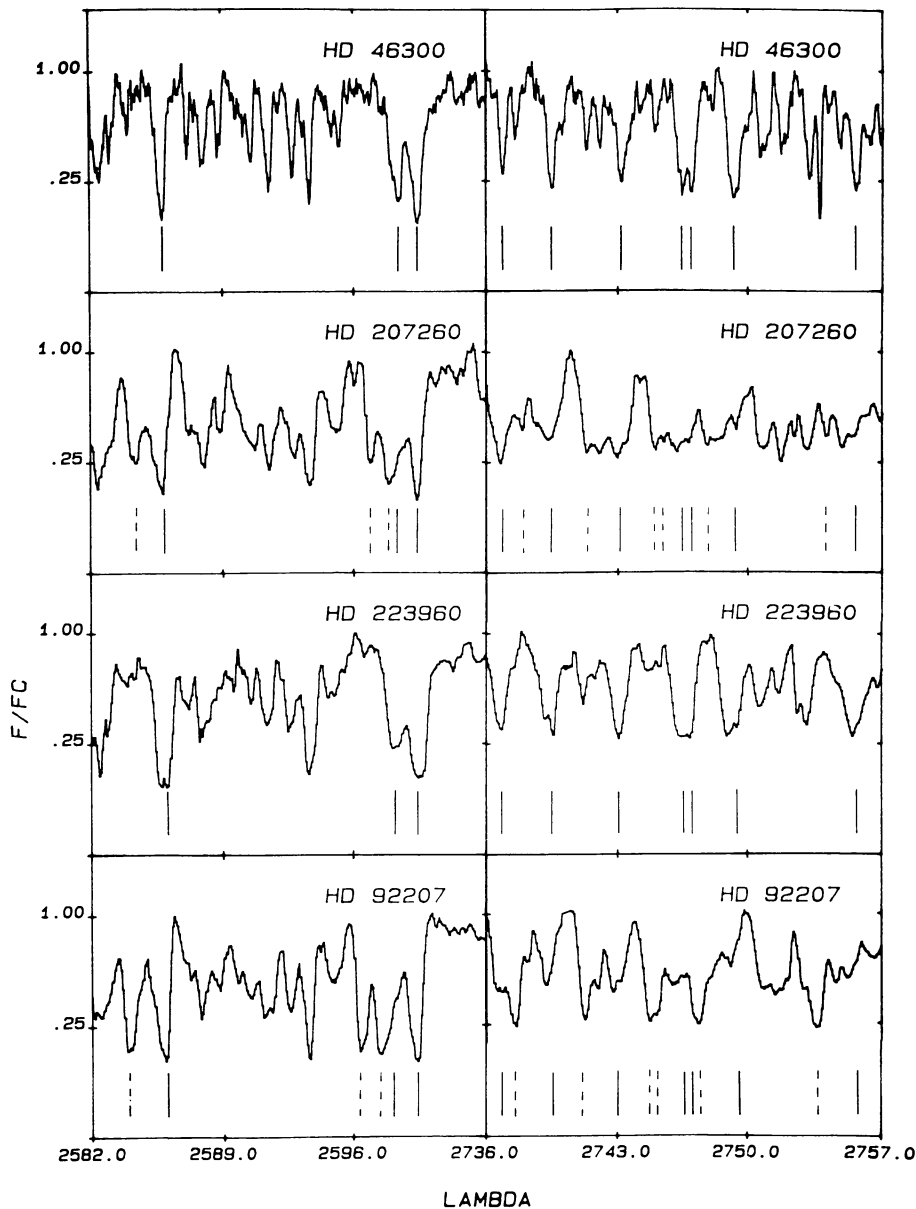
b) In HD 207260 the  $-91 \text{ km s}^{-1}$  Mg II component has been weakly detected in only three Fe II lines (those at 2498, 2585 and  $2743 \text{ \AA}$ ).

c) In HD 21389 and HD 223960 components have been detected in the Mg II lines but not in the Fe II resonance lines.

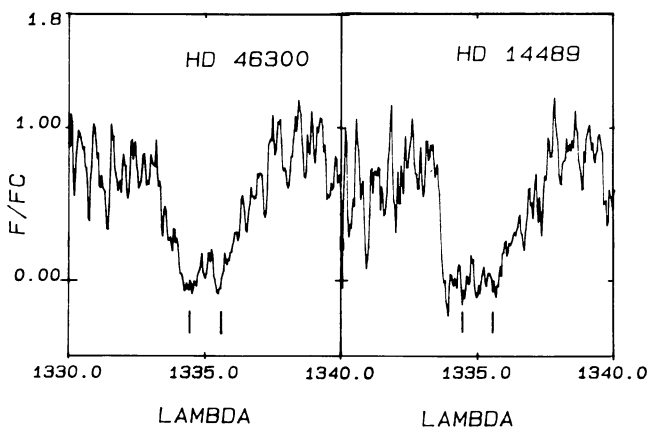
##### 5. Terminal velocity of wind

It has been pointed out in Sect. 3 that the shortward shifted and asymmetric profiles observed for the C II (1), Si II (2) and





**Fig. 2.** Fe II lines in several A-supergiants belonging to the two groups described in the text. In the left and right panels are represented lines of the UV mult. 1 and mults. 62–63 respectively. The rest wavelengths of the lines and of some shortward shifted components are marked with a continuous and a dotted line, respectively. In all figures, an asterisk (\*) denotes a Reseau Mark or a camera artifact

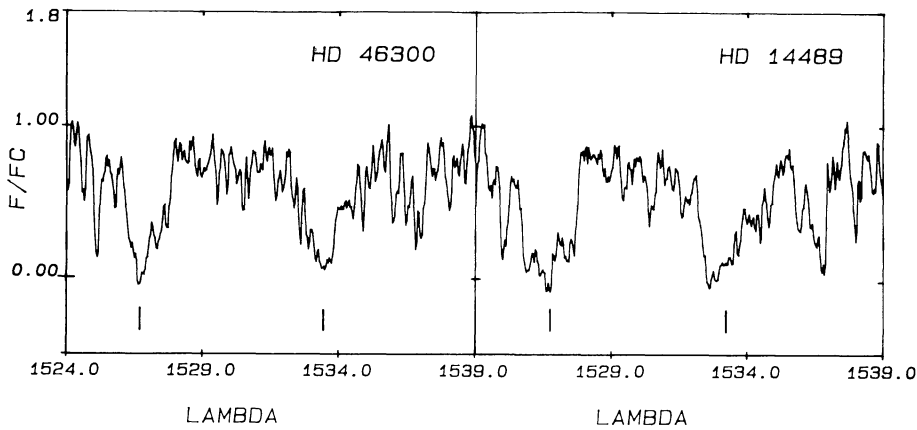


**Fig. 3.** C II lines in HD46300 and in HD14489. The rest positions of the lines have been marked

Mg II (1) lines suggest that these lines are formed in the stellar wind. (See also Praderie et al., 1980; Kunasz and Praderie, 1981).

For line profiles with a deep absorption and a nearly vertical violet edge, the velocity at which the shortward wing reaches the continuum (hereafter  $V_{sw}$ ) is the terminal velocity of the ion (Garmany et al., 1981). Nearly all the A-supergiants of group II have such steep shortward wing on the Mg II, C II and Si II profiles (see Figs. 1, 3, 4), although there are some exceptions which will be discussed later.

To estimate the terminal velocity  $V_t$  we have fitted a local continuum by linear interpolation between selected windows and we have drawn the shortward wing up to the continuum. Since all the lines provide nearly the same values we consider that the terminal velocity of the wind is the mean of the terminal velocity obtained from each ion (see Table 6). Errors in the velocities are introduced mainly during the fitting of the con-



**Fig. 4.** Si II lines in HD 46300 and in HD 14489. The rest positions of the lines have been marked

tinum and the correction of the wavelength scale (see Sect. 2), and they are of the order of 10%. Additional errors could be introduced by the presence of an Fe II line (probably shortward shifted like most of the Fe II lines in A-supergiants) placed near the shortward wing of the 2795 Å Mg II line (see Table 5).

The shortward wing velocities obtained for HD 21389, HD 17378 and HD 223960 are not reliable as terminal velocities because of the shape of the Mg II lines in these stars. Note that profiles with a deep absorption but a smoothly rising violet wing, may or may not provide the correct terminal velocity, depending on how the ionization balance and the velocity change

with radius (Abbott, 1978), moreover in the case of HD 21389 the shortward shifted absorption is not saturated.

Another special case is 6 Cas which will be treated in Sect. 7.

## 6. Variability

Rosendhal (1972) reported the existence of small variations in the H $\alpha$  emission in A-supergiants. These variations were irregular and attributed to microturbulence. Additional evidence of variability has been found in the UV spectrum (from the BUSS

**Table 4.** Components observed in the Mg II and Fe II lines

Star	$M_v$	Date of OBS.	Comp. No.	Fe II $ \langle V_r \rangle \pm \epsilon $	Mg II 2795	2802
HD 59612	-5.1	11/11/78	V1	$ -215 \pm 17 $	-197	-206
			V2	$ -99 \pm 10 $	-94	-109
			V3	$ 0 $	0	0
		13/02/79	V1	$ -209 \pm 13 $	-213	-220
			V2	$ -131 \pm 14 $	-136	-158
			V3	$ 0 $	0	0
		03/03/79	V1	$ -209 \pm 15 $	-218	-206
			V2	$ -124 \pm 10 $	-121	-111
			V3	$ 0 $	0	-28
	15/10/80		V1	$ -211 \pm 15 $	-224	
			V2	$ -130 \pm 15 $	-152	-142
			V3	$ 0 $	0	-13
HD 207260	-6.7	11/10/80	V1	$ -172 \pm 4 $		-169
			V2	$   $		-91
		02/04/84	V1	$ -209 \pm 5 $		
			V2	$ -186 \pm 7 $		
			V3	$ -164 \pm 7 $		
HD 14433	-7.0	30/10/79	V1	$ -203 \pm 15 $		-181
			V2	$ -142 \pm 7 $		-130
			V3	$ -80 \pm 13 $		

Table 4 (continued)

Star	$M_v$	Date of OBS.	Comp. No.	Fe II $ \langle V_i \rangle \pm \varepsilon $	Mg II 2795	2802
HD 223960	-7.1	11/10/80	V1		-220	-220
			V2		-169	-156
			V3		-130	-91
HD 21389	-7.1	13/11/78	V1		-149	-149
			V2		-106	-97
		15/02/79	V1		-196	-210
			V2		-136	-136
			V3		-91	-91
HD 12953	-7.9	29/10/79	V1	$ -221 \pm 6 $		-201
			V2	$ -157 \pm 13 $		-156
			V3	$ -112 \pm 7 $		-104
		11/10/80	V1	$ -206 \pm 4 $	-208	-201
			V2	$ -132 \pm 17 $	-117	-123
			V3			-59
HD 17378	-7.9	15/10/80	V1		-208	-207
			V2	$ -153 \pm 12 $	-143	-156
			V3	$ -98 \pm 13 $		-97
HD 92207	-8.0	04/05/81	V1	$ -222 \pm 14 $		
			V2	$ -30 \pm 8 $		
HD 197345	-8.4	24/06/78	V1	$ -175 \pm 7 $		
		12/10/78	V1	$ -170 \pm 6 $		
		13/11/78	V1	$ -175 \pm 5 $		
			V2	$ -92 \pm 6 $		
			V3	$ -56 \pm 8 $		
		21/06/79	V1	$ -176 \pm 8 $		
			V2	$ -91 \pm 9 $		
		30/10/79	V1	$ -195 \pm 8 $		
			V2	$ -111 \pm 7 $		
			V3	$ -46 \pm 8 $		
		22/04/80	V1	$ -193 \pm 11 $		
			V2	$ -129 \pm 9 $		
		15/05/80	V1	$ -188 \pm 7 $		
			V2	$ -151 \pm 9 $		
			V3	$ -88 \pm 6 $		
		13/10/80	V1	$ -189 \pm 9 $		
			V2	$ -138 \pm 12 $		
		15/10/80	V1	$ -190 \pm 6 $		
			V2	$ -136 \pm 15 $		
		16/10/80	V1	$ -192 \pm 6 $		
			V2	$ -134 \pm 6 $		
		02/04/84	V1	$ -197 \pm 7 $		
			V2	$ -32 \pm 7 $		



**Table 5.** Intense metallic lines near the Mg II (1) lines

Mg II line	Ion	Mult.	Wavelength (Å)	Shift <sup>(a)</sup> (km s <sup>-1</sup> )
2795.523	Fe II	337	2793.239	-243
	Fe II	198	2793.888	-174
	Fe II		2793.928	-169
	Fe I	46	2794.702	-86
	Mn I	1	2794.817	-74
	Fe I	3	2795.005	-54
2802.698	Fe I	94	2795.540	4
	Fe II	198	2799.712	-318
	Fe I	2	2800.467	-238
	Fe I	436	2800.537	-230
	Mn I	770	2801.084	-123
	Fe III		2802.773	9
	Fe I	3	2803.166	51

<sup>(a)</sup> These numbers give the shifts with respect to the 2795.523 or the 2802.698 Mg II line of the intense metallic lines that may blend with true Mg II shifted components

balloon data) by Lamers et al. (1978), who detected changes in the Fe II lines of HD 197345 and HD 87737.

We also have found variations in the IUE spectra of A-type supergiants. We have concentrated our study on the terminal velocity of the wind and on the components of the Fe II lines.

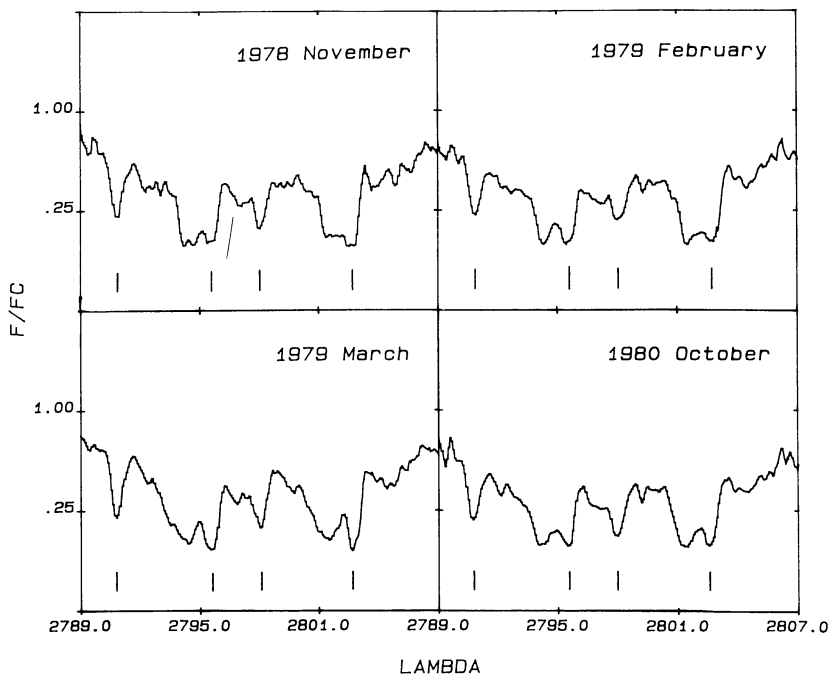
We have selected one star from our sample: HD 197345 ( $\alpha$  Cyg) which is the A-supergiant most frequently observed with IUE. However the observations are not uniformly distributed with time and short term variations cannot be checked. The variations of the terminal velocity in  $\alpha$  Cyg (see Table 6) are within the error bars of the measured values (about 20 km s<sup>-1</sup>). In agreement with this fact, the velocity of the furthest shortward shifted component detected in the Fe II lines remains stable (within the error bars) in all the images. However, the other components suffer significant changes (see Table 4).

In addition, for several stars (HD 59612, HD 12953, HD 207260 and HD 21389) we have measured the terminal velocities shown by the Mg II in two images (see Table 6). Note that, in HD 59612, the terminal velocity increased by a considerable amount from 1978 November until 1979 February (see Fig. 5), while in HD 207260 it decreased from 1980 October to 1982 January and 1984 April.

**Table 6.** Terminal velocity of wind

Star	S.T.	$M_v$	Date of Observation	Mg II $V_t(2795)$ (km s <sup>-1</sup> )	$V_t(2802)$	Si II $V_t(1526)$ (km s <sup>-1</sup> )	$V_t(1533)$	C II $V_t(1334)$ (km s <sup>-1</sup> )	$V_t$ (km s <sup>-1</sup> )
HD 59612	A5 Ib	-5.1	11/11/78	-208	-207				-208
			13/02/79	-273	-246				-260
HD 207260	A2 Iab	-6.7	11/10/80	-285	-285				-285
			12/01/82			-225	-237	-245	-236
			02/04/84	-240	-240				-240
									-279
HD 14433	A1 Ia	-7.0	30/10/79	-273	-285				-279
HD 21389	A0 Iab	-7.1	13/11/78	-221	-181				-201 <sup>a</sup>
			15/02/79	-234	-201				-218 <sup>a</sup>
HD 223960	A0 Ia	-7.1	11/10/80	-286	-259				-273 <sup>a</sup>
HD 14489	A2 Ia	-7.6	10/09/83	-247	-246				-247
			19/12/83			-249	-261	-258	-255
HD 12953	A1 Ia	-7.9	29/10/79	-286	-272				-279
			11/10/80	-292	-272				-282
HD 17378	A5 Ia	-7.9	15/10/80	-286	-266				-276 <sup>a</sup>
HD 92207	A0 Ia	-8.0	04/05/81	-286	-272				-279
HD 223385	A3 Ia	-8.3	09/09/83	-338	-325				-337
HD 197345	A2 Ia	-8.4	24/06/78	-286	-278				-282
			12/10/78	-279	-259				-269
			13/11/78	-273	-246	-282	-283	-272	-271
			21/06/79	-292	-305				-299
			30/10/79	-292	-305				-299
			22/04/80	-308	-305				-307
			15/05/80	-305	-305				-305
			13/10/80	-299	-305				-302
			15/10/80	-305	-285				-295
			16/10/80	-312	-298				-305
			02/04/84	-312	-310				-311

<sup>a</sup> Low quality measures (violet wing not enough sharp)



**Fig. 5.** Variations detected in the Mg II lines of HD 59612. The rest positions of the Mg II lines are marked

We have checked also the velocity of the components of the Fe II lines in these stars. In HD 59612 as in  $\alpha$  Cyg the furthest shortward shifted component remains stable. However in HD 12953 that component changes (see Fig. 6). In HD 207260 we have detected a component at  $-200 \text{ km s}^{-1}$  in 1984 April, which did not appear in 1980 October. All these data are summarized in Table 4.

## 7. 6 Cas (HD 223385)

By contrast with the other stars studied, 6 Cas shows strong P-Cygni profiles in the C IV and Si IV resonance lines (see Fig. 7). Consequently the excitation conditions which prevail in the wind of this star are different than are usual in A-supergiants. This fact was previously reported by Hutchings & Von Rudloff (1980), from IUE low dispersion spectra.

On the other hand, C II, Si II, Fe II and Mg II profiles are different from those observed in the other A-supergiants (compare Fig. 7 with Figs. 1, 2, 3 and 4). The C II resonance lines show a P-Cygni profile. The Si II, Fe II and Mg II resonance lines are broad, shortward shifted and asymmetric. The lines formed in transitions from the 0 eV level are blended with a narrow symmetric absorption component slightly shortward shifted.

The velocity at the shortward wing of all the lines mentioned above has been measured following the method described in Sect. 5. From the Si IV resonance lines we obtain a velocity of about  $-2400 \text{ km s}^{-1}$ . Although the two C IV resonance lines are blended, and the shortward wing may extend to the Si II (UV mult. 2) lines, a terminal velocity of the order of  $-2400 \text{ km s}^{-1}$  is compatible with the observed profile. On the other hand, the terminal velocities measured by means of the Fe II and Mg II resonance lines are  $-270 \text{ km s}^{-1}$  and  $-330 \text{ km s}^{-1}$  respectively (see Table 6).

An explanation for these peculiarities might be that 6 Cas is a spectroscopic binary. The C IV and Si IV profiles, as well as the

terminal velocity of the wind obtained from these ions, are usual for O-stars. Therefore, in a first approach we could consider that 6 Cas is a binary system composed by an O-star and an A-supergiant: the second star will dominate the optical spectrum, while the first one will be the origin of the high excited and shortward shifted lines. In such a case the UV continuum at short wavelengths ( $\approx 2000 \text{ Å}$ ) will be dominated by the O-star, however we have studied the UV continuum of 6 Cas and it is quite similar to that of HD 21389 (A0 Iab): no UV excess has been detected in 6 Cas at short wavelengths relative to the A-supergiants.

An extensive analysis of all the available UV data will follow (Gomez de Castro and Talavera, in preparation).

## 8. Discussion

### 8.1. Structure of the wind

The characteristics observed in the Fe II and Mg II lines make us suspect that all the Mg II lines in A-supergiants may be formed by the superposition of several components (possibly more than two). In this way, the asymmetric and shortward shifted profiles would be caused by blending between broad components like those observed separately in HD 21389 or HD 17378. This hypothesis is supported, in addition, by the detection of two stars HD 14433 and HD 207260 whose  $2802 \text{ Å}$  Mg II line is split into several components while their  $2795 \text{ Å}$  Mg II line is not. (Note that the strength of the  $2795 \text{ Å}$  line is nearly twice the  $2802 \text{ Å}$  one, and therefore separate components are more easily observable in the latter line).

The presence of components and the reported variability suggest that a considerable fraction of the envelope is ejected in 'puffs' or shells in the most luminous A-supergiants. These shells might be produced by an instability in the outer layers of the star, whose characteristics could be similar to the ones of P-Cygni (Lamers et al., 1985) in which the same phenomenology has been detected. The analysis of the Fe II lines in P-Cygni

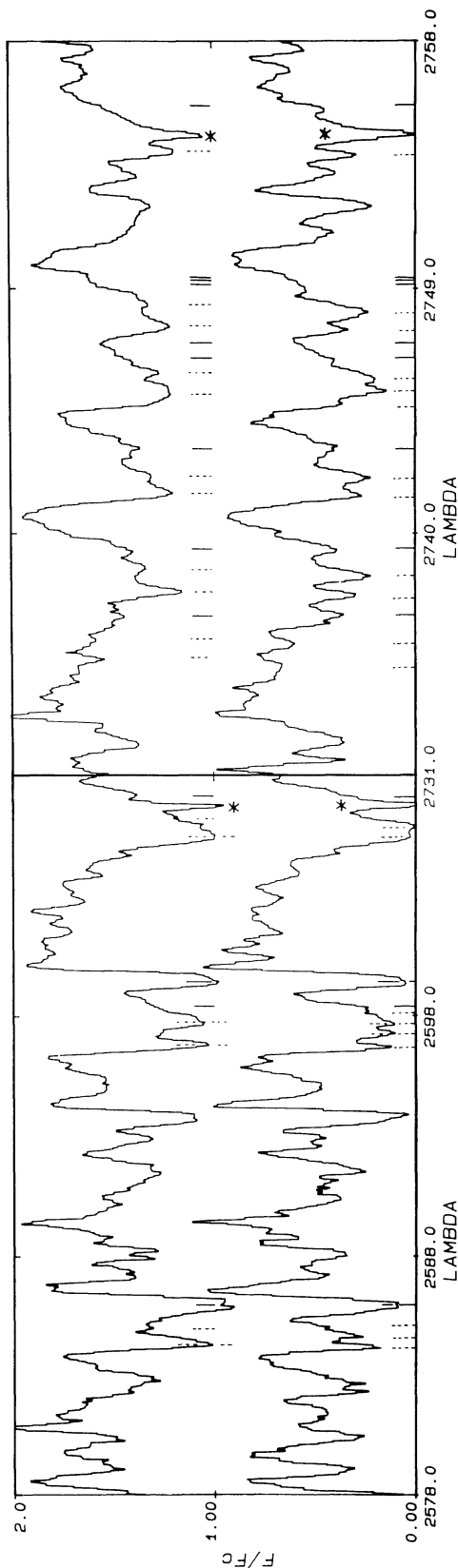


Fig. 6. Variations detected in Fe II lines of HD 12953. Top, Fe II lines in 1979 October. Bottom, the same in 1980 October. (Left, UV mult. 1; Right, UV mult. 63. The rest wavelength of the lines and the shortward shifted components have been marked with a continuous and a dotted line respectively)

has shown the existence of a stable component shortward shifted by  $-205 \text{ km s}^{-1}$  and another variable component whose variations indicate that P-Cygni ejects shells at intervals about a year.

For the time being we have not enough data available to check the periodicity (if it exists) of shell ejections in A-supergiants but from data of Table 4, we could infer that shells are ejected from time to time.

Note that narrow components have been observed also into the P-Cygni profile of C IV, Si IV, N V and O VI resonance lines in O and B supergiants (Underhill, 1975a,b; Lamers et al., 1982). In these stars, components have constant velocity although they show strong changes of intensity. To interpret their observations Lamers et al. proposed a wind model with two components: one diffuse which leaves the star with a velocity of the order of  $0.75V_t$  and another one, dense, whose velocity increases up to a maximum which is the observed terminal velocity of wind. The first wind component would be responsible of the appearance of the narrow component of the line while the second one would be responsible of the observed P-Cygni profile.

A different explanation for the formation of shortward shifted components has been proposed by Underhill and Fahey (1984). They proposed that the components are produced by parcels of gas ejected from source points above the photosphere of a rotating star. These source points are related to 'open' magnetic loops such as in the model used to represent the wind and corona of the Sun.

We want to remark that although the narrow components observed in O and B supergiants have constant velocity, this is not the case in A-supergiants (see Sect. 6). Therefore, none of these models is valid for the variable components detected in the Fe II and Mg II profiles of A-supergiants.

In 1984, Mullan proposed a wind model which could explain the presence of these narrow and variable components. This model is in some way similar to the model outlined by Underhill & Fahey (1984). Mullan (1984) has proposed a non-spherically symmetric model of the envelope-wind complex consisting in the alternance of fast and slow streams similar to the ones observed in the Sun. The mixing of those streams produced by the rotation of the star would lead to the so-called corotating interaction regions (CIR), where the components of the lines could be formed. In this model the shift of the components would vary and that variation would be modulated by the rotation of the star.

That model has been applied successfully to AB Aur, a Herbig Ae premain sequence star, by Praderie et al. (1986) and Catala et al. (1986). We do not possess a systematic series of observations for any A-supergiant and therefore we cannot check the ability of that model to explain the variations observed in the Fe II and also in the Mg II lines.

In any case, the coexistence of narrow and broad components in the line profiles seems to be a phenomenon common to all the stars showing evidence of wind and mass-loss. More work has to be done both on the observational side and on the construction of theoretical models to explain the creation and evolution of components in the line profiles of at least the A-type supergiants.

## 8.2. Radiatively driven winds

In 1975, Castor, Abbott and Klein (hereafter CAK) developed the theory of radiation driven winds to study mass-loss in Of

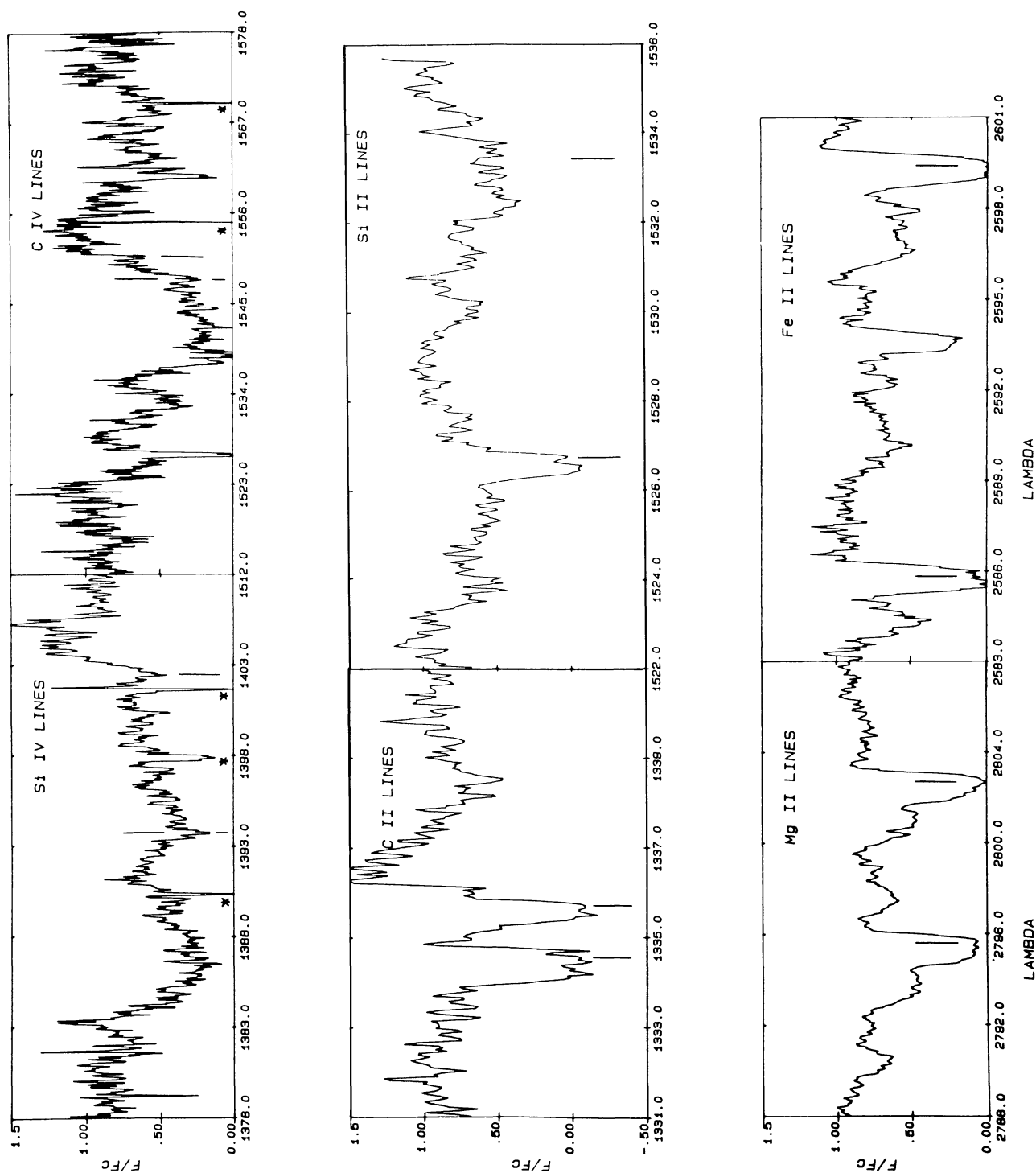


Fig. 7. Main spectral features in the UV spectrum of 6-Cas. Top panel: the C IV and the Si IV lines. Middle panel: the C II and the Si II lines. Note that C II lines show a P-Cygni profile while Si II lines do not show it. Bottom panel: the Mg II and Fe II lines. The rest wavelengths of the resonance lines are indicated

stars. This theory predicts a linear scaling between terminal and escape velocity:

$$V_t^2 = \frac{\alpha}{1 - \alpha} V_e^2$$

where  $\alpha$  points out the dependence between the line force  $M(t)$  and an optical depth  $t$ .

The existence of such linear scaling was quickly checked and proved. In 1978, Abbott found  $V_t/V_e \sim 3$  by studying a sample of 34 stars of spectral types O, B and A (only one A:  $\alpha$  Cyg). In 1981, Garmany et al found  $V_t/V_e \sim 2.6 \pm 0.6$  from the study of O-type stars in OB associations.

However these scaling factors do not agree with the ones predicted by the computations of Abbott (1982). He calculated the line forces for several physical conditions, using a group of lines which was complete for elements H to Zn in ionization states I to VI, and he obtained a ratio  $V_t/V_e$  between 1.1 and 1.4 for O-type stars depending on  $\log g$ ,  $T_{\text{eff}}$  and electronic density.

We have supposed that in the small part of the HR-diagram where A-supergiants are included a linear scaling between  $V_t$  and  $V_e$  can be considered. Figure 8 supports this hypothesis. We have found that:

$$V_t(\text{km s}^{-1}) = 390 - 0.7V_e(\text{km s}^{-1})$$

To obtain this correlation we have not included stars with a low degree of confidence in the measured  $V_t$  values (see Sect. 5).

It is very important to notice that the slope of this correlation is negative, or in other words that the terminal velocity in A-supergiants decreases with increasing escape velocity, and this result is not in agreement with CAK's theory. It can be argued that this discrepancy is caused by observational effects such as the small amount of data (only 7 stars) with nearly the same luminosity and the reported variability, or the errors in the measuring process. Nevertheless, there are several facts which support our conclusion or, at least, support the existence of a change of slope in the dependence between  $V_t$  and  $V_e$  relative to the prediction of the CAK theory. According to CAK theory the slope for A-stars must be about 1 (Abbott, 1982). We note the following:

1. Variations in the terminal velocity have been searched carefully in HD 197345 and have not been found. On the other hand, important variations have been detected in the less luminous stars HD 59612 and HD 207260. This fact makes the observed slope sensitive to changes in the terminal velocity of these stars. However, even in the most unfavourable case, the observed trend is that  $V_t$  decreases or remains constant when  $V_e$  increases. The slope will never reach unity.

2. We have proposed that a considerable fraction of the envelope could be ejected in 'puffs' or shells which will explain the nature of the components observed in Fe II and Mg II lines. In such a case the velocity of the most external shell (of the most shortward shifted component) will supply a parameter to check the importance of the radiation pressure for the acceleration of the wind. However, as the values of Table 7 show, there is no correlation between the escape velocity and the shortward shift of the furthest shifted component.

When Abbott (1978) studied the dependence of  $V_t$  on  $V_e$  for the 34 O, B and A stars included in his sample, he remarked that neither  $\alpha$  Cyg and nor P Cyg agreed with the general trend which he found, namely the relation  $V_t/V_e \sim 3$ . Abbott argued that possibly the masses of  $\alpha$  Cyg and P Cyg had been overestimated

**Table 7.** Velocity at the shortward wing of the main spectral features observed in 6-Cas

Ion	Mult.	Wavelength (Å)	$V_{\text{sw}}$ (km s <sup>-1</sup> )
Si IV	1	1393.755	-2400
Mg II	1	2795.523	-338
		2802.698	-325
Fe II	1	2585.876	-267
Fe II	63	2736.968	-252
		2739.545	-252
		2746.978	-277
		2755.733	-277

because these stars are in the post-core-hydrogen-burning stage of evolution. Pauldrach et al. (1986) have predicted the terminal velocity of P Cyg using a modified theory of radiative driving and are able to reproduce the terminal velocity for P Cyg without introducing special considerations.

In spite of the reasons discussed above, it is clear that a careful analysis of the variability must be performed before arriving at any conclusion. If after further study, the negative slope of Fig. 8 is confirmed, that would mean that radiation driven winds are not applicable to A-type supergiants.

In Table 8, we have summarized our results together with mass-loss rate of several A-supergiants determined from infrared photometry by Barlow & Cohen (1977) and the net strength of H $\alpha$  (absorption below the continuum minus emission above the continuum) taken from Rosendhal (1973).

## 9. Summary and conclusions

From the previous paragraphs we infer that A-supergiants can be classified in two groups:

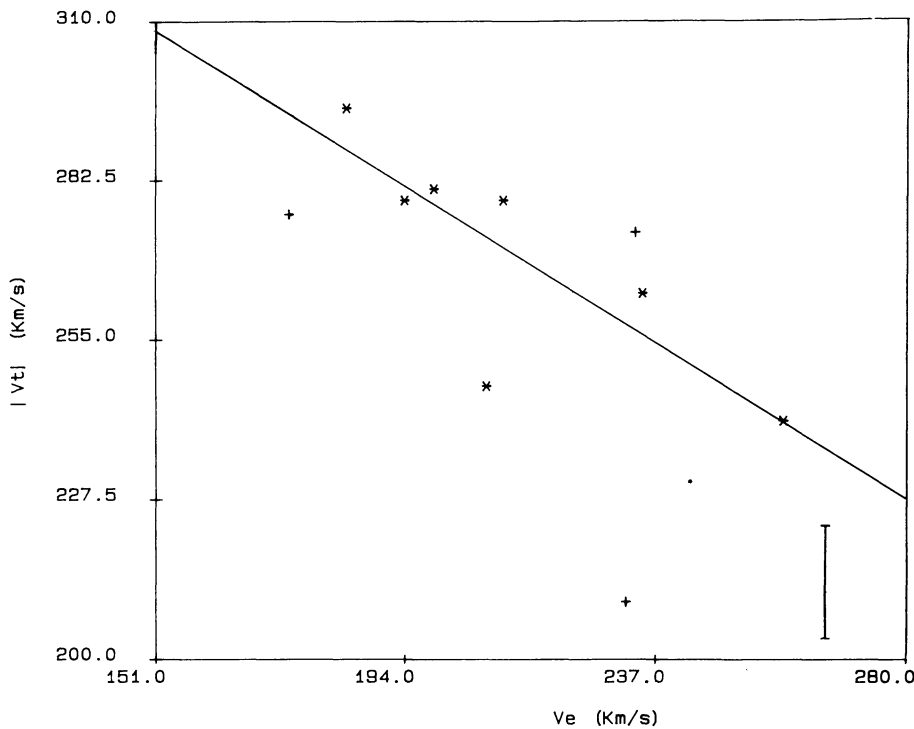
**Group I:** Stars in which Cu II, Fe II, Si II and Mg II lines are symmetric and centered at 0 velocity.

In that group there is no evidence of mass outflow in the line profiles. Low mass-loss rates ( $\sim 4.7 \cdot 10^{-8}$  for  $\eta$  Leo) have been reported by Barlow and Cohen (1979).

Variability has not been studied yet. The stars included in this group are the faintest of the supergiants for which we have observations: HD 46300 and HD 87737.

**Group II:** Stars in which Mg II lines are broad and asymmetric, with the characteristic  $\alpha$  Cyg profile, pointing out the existence of mass outflow. Other lines belonging to singly ionized species show asymmetric shortward shifted profiles; several shortward shifted components are observed clearly in the Fe II resonance lines.

We have observed that the terminal velocity of the wind decreases with increasing escape velocity for stars of this group. This behaviour should be confirmed by studying these stars during a greater amount of time, because of the variability detected both in the terminal velocity of the wind, and in the velocity of the components of the Fe II lines.



**Fig. 8.** Terminal velocities versus escape velocities for the stars of our sample. An error bar is plotted, bottom right. The stars whose terminal velocity is not known accurately (Sect. 5) are marked with a cross

If the negative slope of Fig. 8 is proved to be true, it will mean that the existing theories of radiatively driven winds are not applicable to the A-supergiants as a whole.

The lower limit in absolute magnitude for the appearance of mass-loss in the stars studied is  $M_v = -5.3$  (the  $M_v$  of HD 59612). This is confirmed by the high variability observed in this star and in HD 207260 which is close to that limit. Note the HD 59612 is

one of the stars not fitting the relation between mass-loss, effective temperature and luminosity found by De Jager et al. (1985). Therefore we think that a higher effort must be devoted to study the variability of HD 59612.

Finally we would like to note the existence of one star in our sample which deserves an intensive study because of its peculiar characteristics: HD 223385 (6 Cas).

**Table 8.** Summary

Star	S.T.	$M_v$	$\langle V_t \rangle$ (km s <sup>-1</sup> ) (a)	$\langle V_e \rangle$ (km s <sup>-1</sup> ) (b)	$\langle V_c \rangle$ (km s <sup>-1</sup> ) (c)	Comments	$W_{\text{net}}(\text{H}\alpha)$ (Å) (c)	$dM/dt$ $M_{\odot} \text{ yr}^{-1}$ (d)
HD 46300	A0 Ib	-4.8			-297	Group I	4.73	
HD 59612	A5 Ib	-5.1	-241	-212 ± 14	-259		5.70	
HD 87737	A0 Ib	-5.3			-283	Group <sup>I</sup>		4.7E-8
HD 207260	A2 Iab	-6.7	-263	-190 ± 8	-235		1.94	
HD 14433	A1 Ia	-7.0	-279	-203 ± 15	-194		1.33	
HD 21389	A0 Iab	-7.1	-209		-233		0.45	4.2E-7
HD 223960	A0 Ia	-7.1	-273	-220 ± 5	-233			
HD 14489	A2 Ia	-7.6	-247		-208		0.40	5.2E-7
HD 12953	A1 Ia	-7.9	-281	-207 ± 8	-199		-0.51	8.0E-7
HD 17378	A5 Ia	-7.9	-276	-208 ± 15	-174		3.01	3.2E-7
HD 92207	A0 Ia	-8.0	-279	-222 ± 14	-211			
HD 223385	A3 Ia	-8.3			-182	6-Cas	-0.98	
HD 197345	A2 Ia	-8.4	-295	-186 ± 10	-184		-0.50	6.9E-7

(a)  $\langle V_t \rangle$  is the mean of all the  $V_t$  determined for each star.

(b)  $\langle V_e \rangle$  is the mean of all the  $V_e$  determined for each star.

(c)  $W_{\text{net}}(\text{H}\alpha)$  is the net strength of H $\alpha$  (in the sense absorption below the continuum minus emission above the continuum). These values have been extracted from Rosendhal (1973).

(d) Values of  $dM/dt$  have been extracted from Barlow & Cohen (1977).



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